5   Production Experiments and Results

Experiments evaluated the return velocity and drawdown for experiment conditions and meter positions not addressed in the prototype experiments, after adjusting the physical model to reproduce the prototype. The verification experiments were conducted with the same meter position as the prototype tests. Where to measure the velocities in the vertical was an issue that had to be resolved. Analysis of vertical velocity profile data showed that if the meter was too close to the bed, the maximum change resulting from tow passage may not have been captured. The physical forces study also compared physical model results to a depth-averaged numerical model, the HIVEL-2D (Stockstill, Martin, and Berger 1995). With the exception of the vertical velocity profile experiments, all velocities in the production runs were measured at 60 percent of the local depth below the water surface. This position ensured that the maximum change produced by the tow will be measured and, therefore, directly compared to HIVEL-2D. The following paragraphs detail each experiment series.

Series 1, Rake Experiments

An initial experiment series determined the influence of rake configuration on navigation-induced forces. The rake configuration refers to the shape of the bow on the lead barges. All experiments were conducted with boxed ends at all connections between barges. Previous experiments have shown a significant increase in the resistance of barges with increasing rake angle at medium to high vessel Froude numbers (Latorre and Ashcroft 1981). However, at low vessel Froude numbers that are typical of UMRS tows, results from Latorre and Ashcroft show a small effect of tow configuration on barge resistance. It is not known if this low Froude number effect also applies to rake angle. Data were collected and evaluated for experiments run at variable speeds with bow rake angles of 0.05, 0.08, and 0.16 rad (26, 45, and 90 deg) in conjunction with stern rake angles of 0.16, 0.16, and 0.08 rad (90, 90, and 45 deg), respectively. Tow configuration for these experiments was two wide by four long and actual draft of 2.74 m. The experiments were conducted with no flow and water-surface el 422.9.

The first experiments, also the first experiments in the navigation effects flume, were conducted with the 0.08-rad (45-deg) rake angle. These data were not as consistent as later data, had a high degree of variability, and are not shown on the drawdown and return velocity (X-direction only) plots versus tow speed in Fig-ures 34-38. As discussed in the previous paragraph, these experiments were run with the rake angle on the stern of the barges varying as well as the bow rake angle.

Subsequent experiments and the previously discussed verification experiments were conducted with an 0.08-rad (45-deg) rake angle. By adjusting the model draft until the model return velocity and drawdown matched the prototype data, the 0.08-rad (45-deg) rake angle was forced to mimic whatever rake angle was represented by the prototype data. The distribution of actual rake angles occurring in the prototype was not known.

Analysis of rake angle data will be conducted after rake angle data are collected in the Clark's Ferry physical model.

Series 2, Pool El 418.0

Two experiments (five replicates for each experiment) were conducted at pool el 418.0, with a discharge of 625 cu m/sec, and loaded three-wide by four-long tows. The tow was positioned 1.5 m left of the thalweg and the bollard push propeller thrust was 354.5 kN (79,688 lb). A cross section showing velocity probe locations is shown in Figure 39 and a summary of experiment conditions is shown in Table 16. All velocity probes were set at 60 percent of the depth below the water surface except for probe 4, which was set at 38 percent below the water surface. Wave gauges were set at 70 m right of the thalweg and 100 m left of the thalweg. Ambient, maximum impact velocity, maximum return velocity, and maximum drawdown below normal water level are shown in Tables 17 and 18.

Series 3, Pool El 419.4

Fifteen experiments (five replicates each) were conducted at pool el 419.4, with a discharge of 180 cu m/sec, loaded and partially loaded barges, and two drafts. The cross section is shown in Figure 40 and a summary of experiment conditions is shown in Table 19. Ambient, maximum impact velocity, maximum return velocity, and drawdown below normal water level for each experiment are shown in Tables 20-34. To obtain a representative data set for vector plots shown in Fig- ures 41-57, the five replicate experiments were averaged, and one was selected as the most representative of the mean of the five experiments. Because the vector plots can provide only a finite number of vectors, the maximum value was not always indicated but is provided in the tables. Table 35 summarizes the positions of the velocity probes for each experiment.

Series 4, Pool El 427.0

Twelve experiments (five replicates each) were conducted at pool el 427.0, with discharges of 1,281 and 2,094 cu m/sec, three-wide by five-long barges, and loaded and partially loaded barges. The cross section is shown in Figure 58, and experiment conditions are summarized in Table 36. The ambient velocity distribution is shown in Figure 59. Ambient velocity, maximum impact velocity, maximum return velocity, and drawdown below normal water level for each experiment are shown in Tables 37-48. Vector plots for each representative experiment selected based on the mean of the five replicates are shown in Figures 60-71. Because the vector plots can provide only a finite number of vectors, maximum values were not necessarily shown in the vector plots but are provided in the tables. The position of the velocity probes for each experiment is summarized in Table 49.

Series 5, Vertical Velocity Distribution Experiments

Three experiments (five replicates each) determined the vertical distribution of velocity changes induced by the tow. Table 50 shows the vertical distribution for the downbound *William C. Norman* experiment ND58VD at 81.25 m left of the thalweg. Table 51 shows the distribution of vertical velocity for pool 419.4 experiment KLU488 at 81.25 m left of the thalweg. Table 52 shows the distribution for pool 427.0 upbound experiment KHVU38 at 87.5 m left of the thalweg.

Series 6, Stationary Boat Experiment

Experiment WCNSP evaluated the determination of return velocity and drawdown by running water past a stationary vessel. The advantage was that a highly dynamic event was changed into a steady event where measurements were easier. The average channel velocity was set equal to vessel speed relative to the water. An attempt was made to simulate the conditions in the *William C. Norman* experiments, but the water surface in the flume became relatively rough when the average channel velocity approached the 2.4-m/sec relative vessel speed. The stationary boat experiment was conducted with an average channel velocity of 2.1 m/sec with all other conditions the same as in the *William C. Norman* experiment. Velocity probes were numbered from 1 to 8 starting on the left bank and were positioned at station 62 and probe position PP1 from the pool el 419.4 experiments. The pool elevation was 421.8 and all probes were set at 60 percent of the local depth below the water surface. First the velocity was measured at the eight probes with the tow far downstream of the meters to establish the ambient condition. Then, the bow of the tow was positioned at stations 52-80 in 2-m increments and velocities were measured for about 180 sec (model) at each

station. Finally, the average velocity over the 180-sec time period was determined for each probe at each tow location. The average ambient velocity for each probe was subtracted from the average velocity for each probe at each location. Results are shown in Figure 72 and Table 53 with the maximum value shown at the bottom. The average of the maximums is 0.23 m/sec, which is 1.26 times the computed Schijf average return velocity of 0.183 m/sec. The ratio of 1.26 is consistent with prototype results shown in Chapter 2. Note that the data show the highest return velocities were near the vessel and near the shoreline with lesser magnitude between. Additional stationary boat experiments were not conducted because it is difficult to simulate the higher vessel speeds because of the rough water surface and because boundary conditions are different caused by the channel bottom not moving relative to the boat.

Series 7, Variability of Physical Model Return Velocity Data

The variability of the physical model was evaluated by replicating experiment ND58Q2 nine times. All experiments were run in one day, which eliminated the variability due to setting the flow and stage in the model. Experiment conditions were identical to those for *William C. Norman* and velocity meter locations were the same as the PP1 in the pool el 419.4 experiments. The verification runs were different from those of the *William C. Norman* because the vertical position of the velocity meters was set at 60 percent of the depth from the surface. Results of the nine replicates are shown in Table 54. Comparison of the maximum return velocity average from the nine experiments with the physical model verification run from *William C. Norman* and the *William C. Norman* prototype data are shown in Figure 73. Replicate D was closest to the mean of all nine replicates. Velocity vectors for replicate D are shown in Figure 74.

Series 8, Drawdown Distribution

In conjunction with the nine replicate experiments of ND58Q2 on variability of return velocity data, the wave gauges were positioned at various locations across the channel to measure the distribution of drawdown during vessel passage. Results are shown in Table 55.

Series 9, Numerical Model Output

The November 1994 version of HIVEL-2D simulated the *William C. Norman* condition of experiment ND58Q2. Comparison of maximum return velocity from prototype, physical model, and numerical model is shown in Figure 73. Comparisons of the time-histories between numerical model and

physical model for replicate D are shown in Figures 75-82. Probe positions PP1 (Table 35) for pool el 419.4 were used in the experiments.

HIVEL-2D was also used to assess the adequacy of the navigation effects flume's length. Was the 61-m-long asymmetric section long enough for currents to establish around the tow that are representative of long river reaches? The HIVEL-2D output for the *William C. Norman* downbound tow was plotted at stations 42 to 92 in 10-m increments (Figure 83). A similar plot for an upbound tow traveling at 1.9 m/sec (identical to *William C. Norman* in all other respects) is shown in Figure 84. Ignore magnitudes in Figures 83 and 84 since these are presented in physical model units. Figures 83 and 84 show that the tow reaches a near-equilibrium magnitude of return velocity suggesting that flume length is adequate for measurements at station 62.

A second numerical simulation used the Kampsville section in a reach much longer than represented by the physical model. Results from the numerical model of the long reach and the numerical model of the flume simulation were nearly identical. Comparison of magnitudes of maximum return velocity for the *William C. Norman* from numerical model and prototype showed that the numerical model was 6 percent greater than meter 999; 5 percent greater than meter 332; 2 percent greater than meter 642; 26 percent greater than meter 040; and 4 percent greater than meter 071. The average of the five meters was 9 percent.